The Binary Nature of the Subgiant CH Stars

Robert D. McClure
Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics,
National Research Council, Canada, 5071 W. Saanich Road, Victoria, BC, V0S 1N0
email: mcclure@dao.nrc.ca

ABSTRACT

Repeated radial velocities have been measured for a sample of 10 subgiant CH (sgCH) stars over a period of ∼15 years. Long-term velocity variations are exhibited by all but one star, and spectroscopic orbits have been calculated for six of them. The periods are long, ranging from 876 to 4144 days. The distribution of eccentricities and mass functions for sgCH star orbits are similar to those for giant barium and CH stars, exhibiting significant orbital dissipation relative to normal late-type binaries. It is concluded that all sgCH stars are binaries, and like the barium and CH stars, they have had mass transferred from a former asymptotic giant-branch star.

1. Introduction

From examination of objective prism spectra, Bond (1974) discovered a class of G-type stars with enhanced features of CH and s process elements in their spectra, and with absolute magnitudes placing them near and above the main sequence. With relatively high velocities and weak metal lines, they appeared to be Population II objects and they were referred as subgiant CH (sgCH) stars, because he suggested that they would eventually become classical CH stars when they evolved away from the main sequence and up the giant branch. McClure (1984a, 1985) has reviewed status of the barium, CH and related stars, including the sgCH stars. Abundance analyses have been done by Sneden and Bond (1976), Luck and Bond (1982), Sneden (1983), Krishnaswamy and Sneden (1985), Smith and Lambert (1986), Luck and Bond (1991), and Smith Coleman and Lambert (1993). These analyses of a larger sample of stars indicated that most sgCH stars are moderately metal deficient with [Fe/H] = -0.1 to -0.8, and with s process enhancements similar to the barium stars. The classical CH stars have higher overabundances of the heavy s process elements (Ba through Sm), and C_2 bands (indicating $C/O > 1$) which are lacking in the sgCH stars. The velocities of most of the sgCH stars are also moderate, being more like the old disk than the halo. The essential conclusion of these papers is that despite the name which was originally assigned to them, the sgCH stars are probably the progenitors of moderately metal-deficient barium stars rather than the halo CH stars themselves. A low Li abundance in the sgCH stars was thought to be a problem with their role as progenitors of the barium or CH stars as pointed out by Smith and Lambert (1986), but Lambert, Smith and Heath (1993) have dismissed this as being due to contamination of the Li line by an unidentified line.

The terminology for the sgCH stars has become confusing as a result of the findings of only moderate metal-deficiency. They tend to be referred to in the literature as "dwarf barium stars" (e.g. Jorissen and Boffin 1992, North, Jorissen and Mayor 1996), and overlap with stars referred to as "F Str λ4077" stars (North and Duquennoy 1991). Han et al. (1995) refer to "pre-Ba/CH" stars which undoubtedly includes the sgCH stars.

Regardless of their role as progenitors of the barium stars or of the CH stars, the frequency of binaries among the sgCH stars is of very significant interest. Both the barium and CH stars have been shown to

be long period binaries, and their peculiar abundances are likely the result of mass transfer from a former asymptotic giant-branch (AGB) star whose atmosphere has been contaminated from products of helium shell-flashing (McClure, Fletcher and Nemec 1980; McClure 1983; McClure 1984b; Jorissen and Mayor 1988; Webbink 1986; McClure and Woodsworth 1990). Smith and Demarque (1980) first suggested that the sgCH stars may be mass-transfer binaries since they found it impossible to explain them by internal mixing of helium core-flash material. A program was begun by the present author, therefore, in the early 1980's, to monitor radial velocities of sgCH stars. Some very preliminary results from this program have been mentioned in the literature (McClure 1985, 1989) indicating a high binary frequency, and Luck and Bond (1991) also observed several sgCH stars which appeared to exhibit variable velocity. As a result, most authors have assumed over the last few years that all sgCH stars are binaries. The evidence from these preliminary data, however, is somewhat meager. The present paper presents more complete velocity data for this sample of stars, and sets the binary frequency for the sgCH stars on a firm basis. Results of similar velocity monitoring of sgCH stars has recently been mentioned in a conference paper presented by North, Jorissen, and Mayor (1996).

2. Radial Velocity Observations

The radial-velocity observations were made at the Dominion Astrophysical Observatory in Victoria, using the radial-velocity spectrometer at the coudé focus of the 1.2 meter telescope. See Fletcher et al. (1982) and McClure et al. (1985) for a description of the instrument. It is capable of a precision of about ± 0.3 km s^{-1}, although with the limited integration time for each observation, the observational error for the sgCH stars is closer to double that value. The stellar sample was taken from Bond (1974), supplemented by a few stars from Bond (private communication) that were analyzed later by Luck and Bond (1991). One of these, HD122202, is representative of an earlier class of mid F-type stars with strong Sr, discussed by Bidelman (1981), and more recently by North and Duquennoy (1991). They were referred to by these authors as F str λ4077 stars, but they are almost certainly just earlier examples of G-type sgCH stars.

For most of the stars in this sample Luck and Bond (1991) list radial velocities measured from the same coudé plates from which they analyzed abundances. These velocities are of comparable precision and can be combined with the present data after a small systematic velocity shift of -0.8 km s^{-1} (see below). The radial-velocities and Julian dates (-2400000 days) for each sgCH star are listed in Table 1. Those few entries with Julian dates earlier than 2444000 and marked with an asterisk are from Luck and Bond (1991).

The velocity data are plotted versus Julian date in the upper part of Figure 1. The time span exhibited in these plots is nearly 25 years. Considering that the errors of velocities are approximately the size of the plotted symbols, it is apparent that at least eight of the ten stars exhibit velocity variations representative of long-term binary motion. One further star HD 4395 exhibits some evidence of variable velocity, although the amplitude is small, and no convincing binary orbit could be calculated. The binary frequency is consistent, therefore, with all sgCH stars being binaries, with orbits viewed at random orientations. Luck and Bond (1991) also suggested that three of their stars are velocity variables, although one of these, HD 88446, is the one star in the present analysis that does not appear to exhibit long term variations.

3. Binary Star Orbits

Orbits have been computed for six of the ten sgCH stars, although for those for which the period is comparable to the time span of the observations the orbits should be considered somewhat preliminary. Because the velocity variations for the sgCH stars are very small, one must be careful about systematic differences when combining data from a different program and different instruments. See the discussion, for example, on standard-velocity zero-pints by IAU Commission 30 (Andersen 1990), where uncertainties approaching 1 km s^{-1} are discussed. The orbits were first calculated, therefore, using only the data from the present set of observations, giving the velocities from Luck and Bond (1991) zero weight. Residuals from the velocity curves for their observations were calculated and a systematic difference of +0.85 km s^{-1} was found with a mean error of ± 0.38 km s^{-1}. The apparently constant velocity star HD 88446 also gives a similar positive error (+1.18 km s^{-1}) with respect to the present data for that star, although this residual was not included in the average because a long term variation for the star cannot be ruled out. The Luck and Bond data were all shifted by -0.8 km s^{-1}, therefore, and the orbits were calculated again, giving all observations unit weight. The resulting average residual for the Luck and Bond data from the final orbital calculations is $+0.04 \pm 0.15$ km s^{-1}. The orbital elements for the six stars are listed in Table 2. The velocities as a function of phase, resulting from these solutions are plotted in the lower part of Figure 1, and phases and residuals from the orbital curves are listed for the individual observations in Table 1.

Orbit calculations were attempted for one further star HD 182274, but a unique orbit could not be determined. An orbit with low eccentricity and a period of 8000 days or more is possible, but the amplitude and period are uncertain. It is also possible that the orbit might have very high eccentricity, with the maximum velocity occurring immediately before the present observations were begun, but it could be several more years before this could be confirmed or ruled out.

The cumulative distribution of eccentricities and mass functions are shown in Figure 2 for the sgCH stars along with similar distributions for the barium and CH stars and for normal K giants; the latter distributions are taken from McClure and Woodsworth (1990). In both the eccentricity and mass functions, the sgCH star distributions lie between those for the barium and CH stars. Relative to normal K giants there is evidence, from the lower eccentricities, for orbital dissipation in the sgCH sample, and also for a much more homogeneous distribution of mass functions. McClure and Woodsworth (1990) showed that the barium and CH star mass-function distributions could be modeled with stars of approximately uniform secondary mass, whereas that for K giants required a large range in mass. They found, assuming reasonable masses for the barium and CH primaries, that in both cases the secondary masses are near 0.6 solar masses, typical of white dwarfs. The same must be true for the sgCH stars, given that their mass functions are so similar to those of the barium stars. The distributions exhibited in Figure 2 lend support to the suggestion of Luck and Bond (1991) based on chemical abundances, that the sgCH stars may be precursors to a moderately metal-poor population of giant barium stars. The orbital dissipation supports the hypothesis that these stars have undergone mass exchange.

3.1. Summary

Radial velocity measurements over the last ~ 15 years, have shown that the sgCH stars are likely all binaries. A similar conclusion has recently been suggested in a conference paper by North, Jorissen and Mayor (1996), who have found a high binary frequency among what they refer to as barium dwarfs, which include sgCH stars as well as earlier F-type stars with strong lines of s process elements. The orbital

eccentricities and mass functions for sgCH stars are distributed in a very similar way to those of the barium and CH stars. It is likely that the sgCH stars are precursors to the barium stars as suggested by Luck and Bond (1991), their peculiar abundances being derived from mass transfer of material contaminated through helium shell-flashing in an AGB star that has since evolved to become an unseen white-dwarf.

I wish to thank Murray Fletcher, Les Saddlemyer, Doug Bond, and Frank Younger for help over the years in operation of the radial-velocity spectrometer. I thank Howard Bond for providing me with a list of sgCH stars many years ago prior to publication.

REFERENCES

Andersen, J. 1990 in Transactions of the IAU, XXB, ed. D. McNally, (Dordrecht: Kluwer), p. 267

Bidelman, W. P. 1981, AJ, 86, 553

Bond, H. E. 1974, ApJ, 194, 95

Fletcher, J. M., Harris, H. C., McClure, R. D., & Scarfe, C. D. 1982, PASP, 94, 1017

Jorissen, A., & Mayor, M. 1988, A&A, 198, 187

Jorissen, A., & Boffin, M. J. 1992, in Binaries as Tracers of Star Formation, eds. A. Duquennoy & M. Mayor, (Cambridge: Cambridge Univ. Press), p. 111

Krishnaswamy, K., & Sneden, C. 1985, PASP, 97, 407

Lambert, D. L., Smith, V. V., & Heath, J. 1993, PASP, 105, 568

Luck, R. E., & Bond, H. E. 1982, ApJ, 259, 792

Luck, R. E., & Bond, H. E. 1991, ApJS, 77, 515

McClure, R. D. 1983, ApJ, 268, 264

McClure, R. D. 1984a, PASP, 96, 117

McClure, R. D. 1984b, ApJ, 280, L31

McClure, R. D. 1985, JRASC, 79, 277

McClure, R. D. 1985, in Cool Stars with Excesses of Heavy Elements, ed M. Jashek, & P. C. Keenan (Dordrecht: Reidel), p. 315

McClure, R. D. 1989, in Evolution of Peculiar Red Giant Stars, eds. H. R. Johnson, & B. Zuckerman (Cambridge: Cambridge Univ. Press), p. 196

McClure, R. D., Fletcher, J. M., & Nemec, J. M. 1980, ApJ, 238, L35

McClure, R. D., Fletcher, J. M., Grundmann, W. A., & Richardson, H. E. 1985, in Stellar Radial Velocities, IAU Colloq. 88, eds. A. D. G. Philip, & D. W. Latham (Schenectady: L. Davis Press), p. 49

McClure, R. D., & Woodsworth, A. W. 1990, ApJ, 352, 709

North, P., & Duquennoy, A. 1991, A&A, 244, 335

North, P., Jorissen, A., & Mayor, M. 1996, in The Carbon Star Phenomenon, IAU Symp. 177, ed R. Wing, in preparation.

Smith, J. A., & Demarque, P. 1980, A&A, 92, 163

Smith, V. V., & Lambert, D. L. 1986, ApJ, 303, 226

Smith, V. V., Coleman, H., & Lambert, D. L. 1993, ApJ, 417, 287

Sneden, C. 1983, PASP, 95, 745

Sneden, C., & Bond, H. E. 1976, ApJ, 204, 810

Sneden, C., & Lambert, D. L. 1986, ApJ, 303, 226

Webbink, R. F. 1986, in Critical Observations versus Physical models for Close-Binary Systems, ed. K.-C. Leung, & D. S. Zhai (New York: Gordon & Breach), p. 403

Han, Z., Eggleton, P. P., Podsiadlowski, P., & Tout, C. A. 1995, MNRAS, 277, 1443

This preprint was prepared with the AAS LaTeX macros v4.0.

Table 1. Radial-Velocity Data & Ephemerides for Orbital Solutions

JD −2400000	RV km s^{-1}	O-C	Phase
	HD 4395		
43382.978	−1.6*	....	....
43385.951	−0.90	....	....
45384.648	−2.39	....	....
45583.938	−2.10	....	....
45667.750	−2.63	....	....
45712.590	−3.16	....	....
45938.930	−4.51	....	....
46377.832	−1.31	....	....
46657.941	−0.54	....	....
46717.785	−0.77	....	....
47031.891	1.41	....	....
47116.793	−0.74	....	....
47763.855	−1.03	....	....
47872.645	−0.96	....	....
48232.711	0.25	....	....
49261.852	−1.27	....	....
49647.723	−0.73	....	....
50364.834	−0.81	....	....
50388.804	−0.42	....	....
	HD 11377		
43384.966	−26.4*	−0.02	0.552
45667.773	−27.37	−0.09	0.103
46335.001	−28.94	0.55	0.265
46377.854	−30.50	−1.01	0.275
46704.944	−29.02	0.09	0.354
46802.745	−28.12	0.77	0.378
47031.901	−28.52	−0.28	0.433
47086.798	−29.23	−1.16	0.446
47789.967	−24.63	0.58	0.616
47872.743	−24.14	0.70	0.636
48232.772	−24.02	−0.78	0.723
49261.977	−22.88	0.26	0.972
49647.870	−26.32	−0.22	0.065
50129.639	−29.20	−0.29	0.181
50364.845	−28.96	0.46	0.238
50388.812	−29.01	0.43	0.244
	HD 88446		
43147.950	60.9*	....	....
43200.729	59.70	....	....
43203.851	63.40	....	....
45053.863	61.92	....	....
45116.715	60.60	....	....
45284.039	62.33	....	....
45313.020	61.20	....	....
45367.936	60.14	....	....
45410.867	61.05	....	....
45712.887	60.80	....	....
45803.867	60.91	....	....
	HD 88446		
45849.770	60.99	....	....
46852.046	61.10	....	....
47087.048	60.45	....	....
47141.989	61.06	....	....
47223.879	60.72	....	....
48019.722	61.28	....	....
48387.754	61.61	....	....
50123.860	60.81	....	....
50127.798	61.30	....	....
50128.893	61.04	....	....
50129.830	59.57	....	....
50142.816	60.35	....	....
	HD 89948		
43201.875	18.0*	....	....
43202.795	18.8*	....	....
45313.039	22.00	....	....
46903.774	5.58	....	....
47142.018	15.08	....	....
47223.893	16.10	....	....
50127.889	17.99	....	....
50129.861	18.37	....	....
50142.846	17.54	....	....
	BD+17 2537		
43242.906	4.6*	−0.10	0.303
45367.945	6.67	−0.65	0.486
45368.059	6.69	−0.63	0.486
45452.797	7.18	0.12	0.533
45713.030	4.43	0.42	0.678
45752.855	3.56	0.31	0.700
45803.873	1.51	−0.66	0.729
45849.775	1.03	−0.08	0.754
46234.865	−7.45	−0.52	0.969
46875.962	5.96	0.61	0.326
47141.945	7.47	0.15	0.474
47223.930	7.21	0.04	0.519
47260.945	7.12	0.13	0.540
47316.768	7.02	0.43	0.571
48019.740	−6.25	0.62	0.962
48387.766	−1.31	−0.40	0.167
49560.747	−1.92	−0.02	0.821
50128.943	−2.72	−0.31	0.137
50142.930	−1.51	0.52	0.145
	HD 122202		
43240.847	−11.3*	−0.34	0.090
45368.043	−13.94	−0.31	0.739
45411.039	−13.52	0.55	0.773
45452.871	−14.19	0.21	0.805
	HD 122202		
45713.093	−12.20	0.75	0.007
45752.861	−12.05	0.19	0.038
45803.886	−10.64	0.63	0.077
45849.793	−10.86	−0.43	0.113
46234.875	−7.64	0.79	0.411
46875.983	−14.81	−0.34	0.908
47223.943	−8.58	0.53	0.178
47260.961	−9.44	−0.76	0.207
47316.787	−7.83	0.39	0.250
48019.750	−14.56	−0.25	0.795
48387.790	−11.44	−0.24	0.080
49560.771	−13.87	−0.56	0.990
50130.019	−9.63	−1.00	0.431
50142.991	−8.55	0.19	0.441
	HD 182274		
42675.698	−13.9*	....	....
42676.657	−14.3*	....	....
42999.753	−12.6*	....	....
45178.719	−13.88	....	....
45205.742	−15.18	....	....
45284.637	−16.97	....	....
45452.949	−18.77	....	....
45583.711	−18.49	....	....
45667.574	−17.49	....	....
45803.991	−17.68	....	....
45915.778	−19.43	....	....
46040.628	−18.22	....	....
46334.758	−18.09	....	....
46657.844	−19.46	....	....
46698.664	−19.03	....	....
46717.659	−18.76	....	....
46970.873	−19.55	....	....
46990.781	−19.53	....	....
47005.941	−20.77	....	....
47086.803	−19.41	....	....
47317.918	−19.47	....	....
47377.791	−18.94	....	....
47789.737	−19.20	....	....
48019.984	−18.74	....	....
48089.833	−19.64	....	....
48162.694	−19.06	....	....
49175.894	−17.40	....	....
49261.682	−16.82	....	....
49560.788	−16.11	....	....
49647.656	−17.39	....	....
50124.083	−15.76	....	....
50129.095	−15.04	....	....
50364.696	−14.51	....	....
50388.590	−14.12	....	....

Table 1—Continued

JD −2400000	RV km s^{-1}	O-C	Phase	JD −2400000	RV km s^{-1}	O-C	Phase	JD −2400000	RV km s^{-1}	O-C	Phase
	HD 202020				**HD 204613**				**HD 216219**		
43055.722	−21.5*	0.48	0.030	46704.710	−93.09	−0.41	0.118	44428.938	−4.13	0.06	0.645
45583.844	−18.52	−0.15	0.255	46717.710	−92.40	−0.06	0.133	44485.801	−4.48	−0.15	0.660
45612.766	−18.26	0.32	0.269	46970.918	−88.15	−0.02	0.421	44606.641	−5.29	−0.60	0.691
45667.582	−18.73	0.36	0.295	46980.960	−89.06	−0.96	0.433	44751.973	−5.44	−0.19	0.728
45915.875	−22.36	0.19	0.415	47005.901	−87.93	0.16	0.461	44781.895	−6.07	−0.69	0.736
46040.610	−25.32	−0.70	0.476	47086.819	−88.51	−0.05	0.553	44870.773	−5.69	0.10	0.759
46334.784	−27.54	1.49	0.618	47214.710	−90.35	−0.03	0.699	44935.742	−5.73	0.39	0.776
46657.855	−31.03	−0.25	0.775	47317.951	−92.83	−0.20	0.816	45069.031	−6.54	0.30	0.810
46704.694	−30.56	0.01	0.798	47377.833	−94.11	−0.21	0.884	45583.852	−9.85	−0.29	0.943
46717.666	−30.81	−0.32	0.804	47763.850	−89.01	−0.22	0.324	45667.793	−10.46	−0.58	0.965
46970.913	−26.91	−0.10	0.927	48162.793	−92.27	−0.42	0.778	45938.833	−11.21	−0.76	0.035
47005.822	−25.67	0.38	0.943	48232.697	−93.83	−0.38	0.858	46377.843	−9.19	0.53	0.148
47317.945	−20.06	−0.55	0.095	49175.929	−94.30	0.19	0.932	46657.892	−8.66	−0.18	0.221
47763.838	−19.50	−0.05	0.311	49261.773	−93.90	0.41	0.030	46704.702	−7.72	0.52	0.233
48162.783	−25.62	−0.05	0.504	49560.953	−88.33	0.04	0.370	46717.714	−7.65	0.53	0.236
49175.900	−23.78	−0.16	0.995	50130.073	−95.07	−0.64	0.018	46970.947	−6.74	0.13	0.302
49560.915	−18.08	−0.09	0.181	50364.719	−89.54	−0.26	0.285	46980.968	−7.29	−0.47	0.304
50364.707	−28.14	−0.43	0.571	50388.604	−88.93	−0.01	0.313	47005.907	−6.83	−0.14	0.311
50388.599	−28.43	−0.38	0.582					47086.824	−6.81	−0.52	0.331
					HD 216219			47317.956	−5.21	0.05	0.391
	HD 204613			42675.765	−9.0*	0.02	0.192	47377.839	−5.03	0.00	0.407
43385.862	−88.1*	0.53	0.339	42676.720	−9.7*	−0.69	0.192	47763.842	−4.25	−0.23	0.506
45178.992	−87.85	0.45	0.381	42677.855	−9.2*	−0.19	0.192	48162.788	−4.05	−0.09	0.609
45314.625	−87.91	0.43	0.535	44026.965	−4.02	−0.14	0.541	48232.689	−4.04	0.02	0.628
45583.875	−91.98	1.16	0.842	44073.898	−3.47	0.38	0.553	49175.923	−8.26	−0.09	0.871
45667.801	−94.73	−0.20	0.937	44085.922	−3.95	−0.10	0.556	49261.783	−7.99	0.65	0.893
45917.827	−89.51	0.87	0.222	44110.844	−3.21	0.64	0.563	49560.963	−9.22	0.74	0.971
45938.838	−90.61	−0.69	0.246	44141.934	−3.64	0.21	0.571	50364.714	−8.68	0.57	0.178
46334.768	−90.28	0.00	0.697	44173.801	−4.04	−0.18	0.579				
46657.877	−93.26	0.52	0.065	44191.676	−3.43	0.44	0.584				

*Velocities marked by an asterisk are from Luck and Bond (1991)

Table 2. Orbital Elements for sgCH Stars

Star	P (days)	γ (km s^{-1})	K (km s^{-1})	e	ω (deg)	T(JD) (-2400000^{d})	a sin i (Gm)	f(m) ($M_\odot$)
HD 11377	4140±118	−25.88±0.27	3.88±0.52	0.16±0.08	65±36	45240±437	218±30	0.0241±0.0097
BD +17°2537	1796±12	1.13±0.13	7.17±0.22	0.14±0.02	186±24	46291±128	175.3±5.6	0.0668±0.0063
HD 122202	1290±9	−11.15±0.18	3.34±0.23	0.09±0.08	238±62	46994±205	59.0±4.2	0.0049±0.0010
HD 202020	2064±10	−24.49±0.14	6.45±0.20	0.08±0.04	279±19	47122±105	182.0±5.6	0.0568±0.0052
HD 204613	878±4	−90.96±0.11	3.29±0.15	0.13±0.05	192±21	47479±49	39.4±1.8	0.0032±0.0004
HD 216219	3871±39	−6.96±0.08	3.31±0.13	0.06±0.03	159±29	45803±308	175.8±7.1	0.0145±0.0017

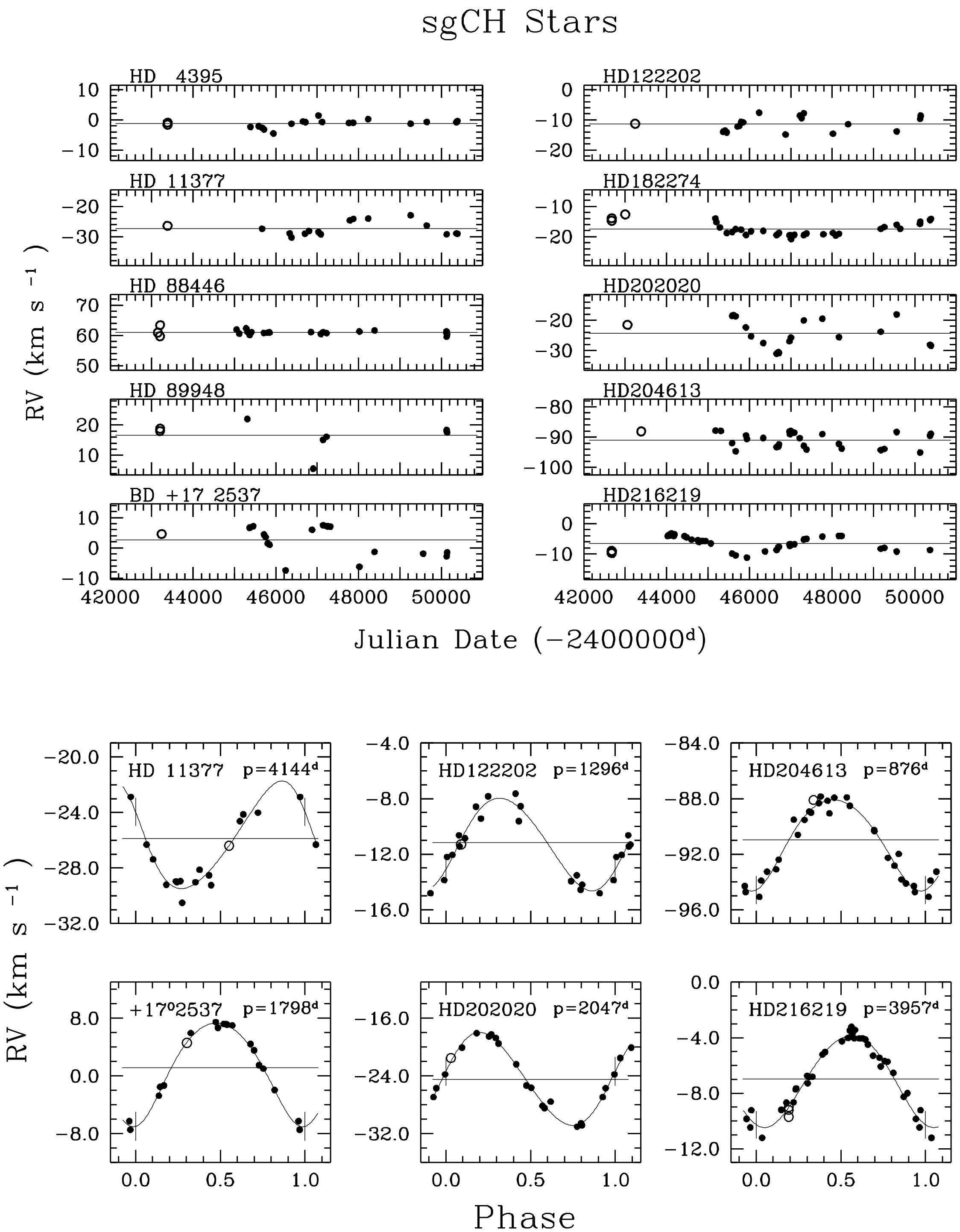

Fig. 1.— Radial Velocities versus Julian dates for sgCH stars are shown in the upper part of the figure. In the lower part, Radial Velocities versus Phase are shown for the computed orbits (solid curves) from the elements listed in Table 2. The observed velocities from which these orbits were calculated are plotted as dots for the present velocities, and open circles for the velocities taken from Luck and Bond (1991).

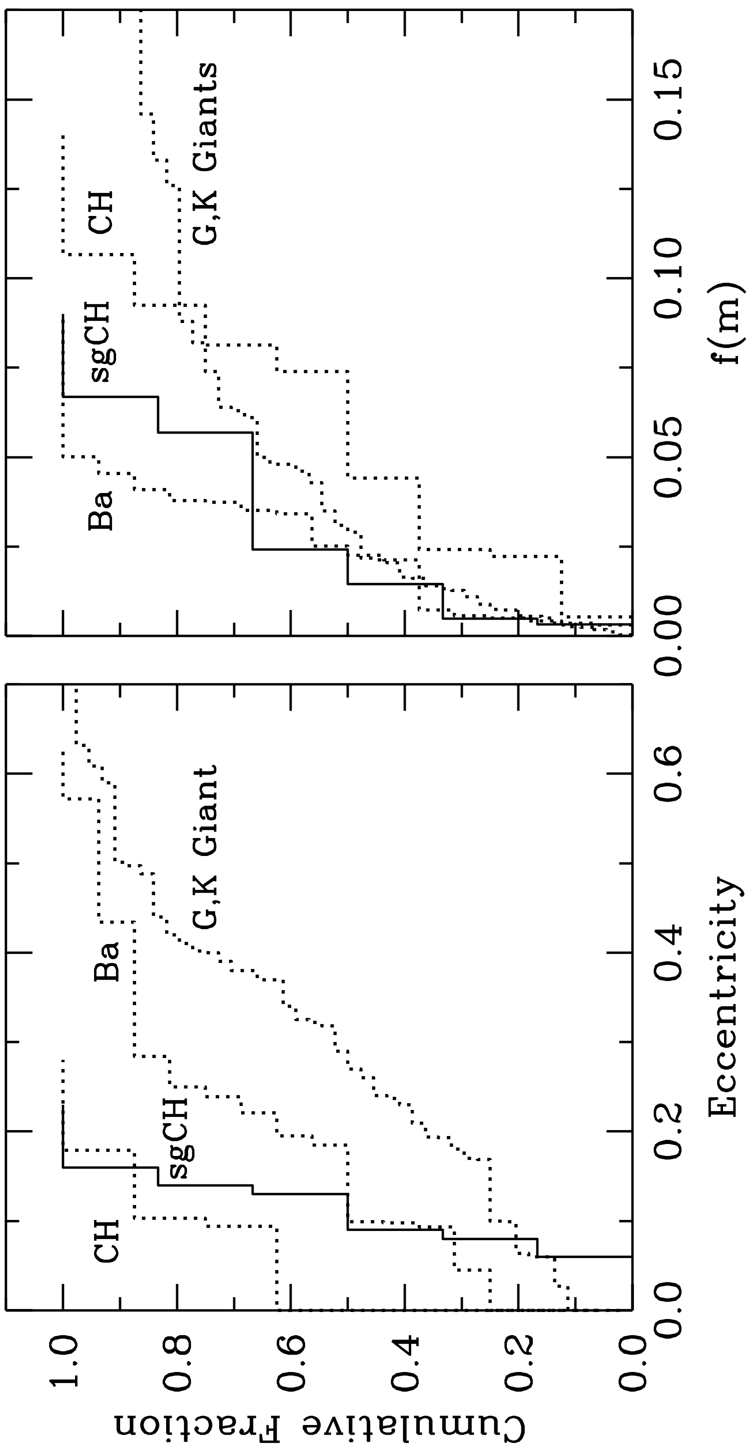

Fig. 2.— On the left, the fraction of stars with eccentricities less than a given eccentricity for sgCH stars (solid curve), CH stars, barium stars and normal G, K giants (dotted curves). On the right: the same except for mass function rather than eccentricity.